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REFERENCE NO. 68-12

CURRENT MEASUREMENTS FROM MOORED BUOYS

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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by

N. P. Fofonoff

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TECHNICAL REPORT

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CURRENT MEASUREMENTS FROM MOORED BUOYS

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Abstract

Since January 1965, a program has been underway at the Woods Hole Oceanographic Institution, to measure currents at a limited number of fixed sites on a year round basis. Initially, one site was instrumented with both surface and subsurface moorings. The program has now been expanded to 4 major sites, extending along 70°W, from 39°20'N to the Hatteras Abyssal Plain at 30°N. In nearly three years of operation, a total of 65 moorings have been placed at the working sites, for periods up to six months. Recoveries from these sites have provided many velocity records of excellent quality.

The repetitive exposure of moorings of essentially similar design under relatively standardized conditions has served to define clearly the design and operational problems that are inherent in such a program.

A brief account is given of some of the problems encountered in routine buoy setting operations, and some of the results obtained from the measurements.

INTRODUCTION

Oceanographers have long sought effective means of measuring currents within the ocean. So much of the dynamics of ocean circulation can only be understood in terms of the velocity field and the forces acting to maintain or change it. The development of moored buoy systems to measure currents over extended periods of time has provided a powerful and sensitive tool to examine the distribution and variation of ocean currents. During the past few years, techniques of data acquisition and processing have been developed to examine the frequency spectrum of velocity fluctuations over six decades of frequency (0.001 to 1000 cycles per hour). Much remains to be done in terms of improving hardware, instrumentation and techniques of analysis. However, the basic questions of usefulness of the data for scientific research have been answered. Many new phenomena are now accessible to measurement.

MEASUREMENT PROGRAM

In January 1965, a program of current measurement started at Site D (39°20'N, 70°W) with the objective of obtaining year round records at several fixed "standard" depths. Initially, moorings were replaced at monthly intervals but logistic problems dictated a longer exposure period (two months) to permit time for procurement and preparation of mooring gear. Moorings were exposed for two, four and even six months in some of the trials.

In February 1966, a second site was instrumented south of the Gulf Stream at 36°N, 70°W (Site J). Moorings at Site J have not been successfully maintained, probably because of the strong currents that occur frequently through Gulf Stream meanders or eddies shed from the Stream. In 1967, moorings were placed at two additional sites at 33°N, 70°W (Site M) and 30°N, 70°W (Site P). Measurements were extended along the 70th meridian over the Hatteras Abyssal Plain to minimize the effect of bottom topography in the initial series of measurements.

In addition to the major sites, small gasoline-filled floats were used to suspend current meters off the bottom under the Gulf Stream. These measurements have been carried out at 38°30'N, 70°W (Site F), 38°N, 70°W (Site G) and 37°30'N, 70°W (Site H).

TYPES OF MOORINGS

Moorings with surface floats, usually toroids, have been set at all major sites so that winds and current near the surface could be monitored. Surface float moorings were instrumented below the surface with current meters and frequently with temperature, pressure and tension recorders. Subsurface float moorings have been used at Site D only. All moorings are equipped with radio and acoustic beacons and acoustic command releases. Both surface and subsurface moorings were used for short-term experiments requiring high sampling rates or special instrumentation.

In the course of two and one half years of operation, 40 long-term moorings, 10 bottom (gasoline) and 15 short-term moorings have been set at the various sites. A total of 226 sensing devices of various types were exposed. Of these, 134 were retrieved for an overall recovery rate of about 60%. Currents from near surface to near bottom have been obtained for all seasons of the year.

Although the data collected are of considerable interest, the purpose of the present paper is to document the operational aspect of the program as an example relevant to the design of future larger-scale buoy networks. The buoys used in the program are relatively small in size to permit handling from a variety of ships in unfavorable weather conditions frequently encountered in winter. The floats range to half a ton in weight with buoyancy of 3000 to 5000 lbs for surface floats; 800 to 1400 lbs for subsurface floats and 200 to 400 lbs for the bottom installations. The mooring line is usually a combination of 1 X 19 steel cable jacketed with plastic and plaited or braided nylon rope. The standard steel cable used has a breaking strength of about 4000 lbs, although moorings have been set with cables of 2000 to 12,000 lbs breaking strength. Nylon rope is used in both surface and subsurface moorings below 1500 to 2000 meters. Moorings are anchored with cast iron Stimson anchors weighing up to 3000 lbs, depending on the type and location of the mooring. Moorings are launched anchor last, allowing the anchor to fall freely to the bottom. In some cases, ground lines have been attached to the moorings. Recently, several moorings were set anchor first to permit closer spacing of instruments and moorings.

RECOVERY STATISTICS

Recovery of short-term moorings, exposed for two weeks or less, is nearly 100% (Table I). Survival has been found to depend strongly on duration of exposure and type of mooring. For longer exposures, the recovery rate drops sharply. Sensor recovery from subsurface moorings averages 60% of sensors exposed (Table II). Returns from surface float moorings (Tables III and IV) and bottom installations (Table V) are disappointingly low.

A listing of failure modes is given in Table VI. It is evident that failure of the mooring line exceeds all other causes combined in determining loss rates. Clearly, corrosion and fatigue must play a dominant role in causing breakage. However, the factors that determine the rates of corrosion and fatigue are not well understood. Experience at sea is contradictory. As an extreme example, Mooring 190, at Site D, survived 142 days exposure with little deterioration of cable terminations. Its replacement, Mooring 198, failed in 21 days and was recovered adrift by a merchant vessel. The terminations were severely corroded. Corrosion rates differed by at least an order of magnitude in the two cases.

Increasing the cable strength seems an obvious solution. Yet moorings set in 1967 south of the Gulf Stream (Table IV) with cables of 8000 to 12,000 lbs breaking strength did not result in improvement of recovery statistics. Tensions telemetered from Site M (Mooring 225) did not exceed 25% of breaking strength over a period of six weeks during which telemetry signals were received. The mooring failed during the last two weeks and was later sighted adrift. It was not recovered. In contrast, Mooring 219, set with standard cable (4000 lbs b.s.) survived a 74 day exposure in which peak tensions approached 70% of breaking strength. Mooring 238 (Site P), set with high-strength cable, was recovered after 61 days. The cable and terminations showed very little corrosion or deterioration.

Such results suggest a complex interaction of factors determining survival. The extreme variability of outcome of sea trials has made definitive experimentation difficult to carry out. Lack of quantitative knowledge of the effects on both fatigue and corrosion of inserting concentrated masses such as current meters into the mooring line, inhibit corrective design changes. Evolution of mooring design would be speeded considerably by active recovery systems that would permit recovery and postmortem in cases of failure. Too often, no portion of the mooring is recovered to pinpoint failure mode.

CONCLUSIONS

The relatively high recovery rate of subsurface moorings compared with moorings set with surface floats suggests that the major causes of failure are associated with enhanced rates of corrosion and fatigue within the surface layers. It is tempting to conclude that exposure to higher temperatures and wave action are the principal factors involved, but results of sea trials are contradictory. Other factors may be involved. The lack of consistent survival of moorings at sea remains the single major obstacle to large-scale application of moorings for scientific research.

Eventual success of a long-term program of measurement from moored buoys depends on a careful integration of scientific application and engineering development. It is essential that quantitative data on mooring behavior in a deep-sea environment be accumulated as a basis for design of improved mooring systems.

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Table I. SHORT TERM MOORINGS

Mooring Number	Month Set	Duration (Days)	Recovery Complete	Recovery Partial	Recovery Lost	Recovery Sensors	Comments
	1965						
177	Feb	3		X		1/2	Vibration fatigue at termination;shallow water, subsurface mooring.
183	May	2	X			2/2	Telemetry test mooring.
	1966						
194	Feb	1	X			6/6	Site J. High sampling rate.
196	Apr	2	X			1/1	Tripod mooring in shallow water; wind measurements.
201	May	2	X			6/6	Short-term current and temp. reading.
208	Aug	2	X			2/2	Measurement of induced potential along vertical.
214	Dec	2	X			4/4	Temperature data.
216	Dec	1	X			6/6	
						28/29	RECOVERY RATE: 97%
	1967						
231	Apr	1	X			4/4	High frequency sampling of wind and surface current.
239	Jun	9	X			3/3	Spatial structure of tidal currents.
240	Jun	9	X			4/4	"
244	Jun	9	X			4/4	"
249	Jul	7	X			6/6	SCOR 21 Current meter intercomparison.
250	Jul	7	X			5/5	" "
251	Jul	7	X			6/6	" "
						32/32	RECOVERY RATE: 100%

Table II. SUBSURFACE FLOAT MOORINGS
Site "D" (39°20'N, 70°00'W)
Depth: 2600 m

Mooring Number	Month Set	Duration (Days)	Recovery Complete	Recovery Partial	Recovery Lost	Recovery Sensors	Comments
	1965						
175	Jan	14		X		1/3	Wire corrosion. Recovered by dragging.
179	Feb	24	X			4/4	
180	Mar	33	X			3/3	
182	Apr	?			X	0/5	No trace.
184	Jun	56	X			4/4	
187	Aug	?			X	0/4	No trace.
189	Oct	54	X			5/5	
191	Dec	73		X		1/3	Released into storm. Cable parted.
						18/31	
							RECOVERY RATE: 59%
	1966						
193	Feb	137	X			4/4	Released by timer backup. Fittings strongly corroded.
200	Apr	?			X	0/5	Cable failure. Beacon heard on bottom.
203	Jun	67	X			4/4	
210	Aug	38	X			5/5	
212	Oct	60	X			4/4	
215	Dec	?			X	0/4	Release jammed by oversize ring.
						17/26	
							RECOVERY RATE: 65%
	1967						
220	Feb	59	X			6/6	
233	Apr	?			X	0/5	Beacon heard on bottom.
243	Jun		On station				

Table III. SURFACE FLOAT MOORINGS

Site "D" (39°20'N, 70°00'W)
Depth: 2600 m

Mooring Number	Month Set	Duration (Days)	Recovery: Complete	Recovery: Partial	Lost	Recovery Sensors	Comments
	1965						
174	Jan	0			X	0/1	Mooring did not anchor. Cable cut too short.
184	Apr	168		X		3/3	Cable parted on recovery. Severe corrosion at terminations.
188	Oct	53		X		3/3	Unable to break weak link. Cable was cut.
190	Dec	142	X			1/1	Cable in good condition.
						7/8	
							RECOVERY RATE 88%
	1966						
198	Apr	21		X		3/4	Recovered adrift. Severe corrosion.
202	Jun	47		X		2/5	Cable parted during recovery. Corrosion.
209	Aug	?			X	0/5	Cable or float failure.
211	Oct	~50		X		2/5	Recovered adrift. Cable failure.
213	Oct	~40		X		2/6	Recovered adrift near Bermuda. Possible failure of current meter sensor cage.
						9/25	
							RECOVERY RATE 36%
	1967						
232	Apr	20+			X	0/6	No trace.
242	Jun	37+	On station.				

Table IV. SURFACE FLOAT MOORINGS SOUTH OF GULF STREAM

Depth: 4500 to 5500 m

Mooring Number	Month Set	Duration (Days)	Recovery Complete	Recovery Partial	Recovery Lost	Recovery Sensors	Comments
	1966						
195	Feb	67	X			4/4	Current meter tie rod broken.
199	Apr	26		X		5/7	Recovered adrift. Nylon rope failure.
206	Jun	?			X	0/8	
207	Aug	20+			X	0/9	Radio beacon failed during hurricane.
219	Dec	74		X		1/1	Tension telemetry.
						10/29	
							RECOVERY RATE: 34%
	1967						
224	Feb	?			X	0/3	No trace.
225	Feb	50+			X	0/4	Adrift.
236	Apr	?			X	0/2	Adrift.
237	Apr	?			X	0/4	Adrift.
238	Apr	61	X			5/5	Tangle at wire-nylon junction.
247	Jun		On station				
						5/18	
							RECOVERY RATE: 28%

Table V GASOLINE FLOAT MOORINGS

Float Depth: 4000-4200 m

Mooring Number	Month Set	Duration (Days)	Recovery: Complete	Recovery: Partial	Recovery: Lost	Recovery Sensors	Comments
	1966						
192	Jan	43	X			1/1	Site F.
204	Jun	?			X	0/1	No trace.
205	Jun	44	X			1/1	Site H.
217	Dec	?			X	0/1	Beacon heard on bottom.
218	Dec	?			X	0/1	No trace.
						2/5	
							RECOVERY RATE: 40%
	1967						
222	Feb	?			X	0/1	Beacon heard on bottom.
234	Apr	?			X	0/1	" " " "
235	Apr	?			X	0/1	" " " "
245	Jun				X	0/1	" " " "
246	Jun		On station ?				
						0/4	
							RECOVERY RATE: 0%

Table VI MOORING FAILURE MODES

(a) Mooring Cable: Failure above acoustic beacon. Float not recovered.

No.	Site	Comments
200	D	Non-standard cable used because of shipment delay. Subsurface.
206	J	Steel cable (4,000 lb b.s.). Nylon rope.
207	J	" " " " " " "
209	J	" " " " " " "
225	M	" " (8,000 " ") " "
233	D	Conical surface float.
236	J	Steel cable (12,000 lb b.s.). Nylon rope.
237	M	Steel cable (8,000 lb b.s.). Nylon rope.

(b) Failure of Steel Cable. Float recovered.

No.	Site	Comments
177	Vineyard Sound	Parted at termination. Vibration in strong current.
181	D	Parted at 10 m termination during recovery. Corrosion.
191	D	Parted at 100 m in storm. Subsurface.
197	D	Anchor tag line parted during launch. Replaced by nylon for greater compliance in subsequent moorings. Subsurface.
198	D	Parted at 100 m. Severe corrosion at terminations.
202	D	Parted at 10 m during recovery.Corrosion at termination.
211	D	Parted at 10 m. Recovered adrift.
219	J	Parted at 2,000 m during recovery. No release used.
226	P	Steel cable (8,000 lb b.s.) parted during launch.

(c) Failure of Nylon Rope. Mooring recovered.

No.	Site	Comments
199	J	Parted at 1500-2000 m shot. Fishbite?
238	P	Parted at acoustic release during recovery. Release failed to trigger on command.

(d) Failure of Instruments or other Hardware.

No.	Site	Comments
178	D	Shackle opened by shearing off cotterpin during launch. Mooring recovered.
195	J	Current meter tie rod broken. Instrument flooded. Mooring recovered.
213	D	Parted at 10 m. Rotor and vane cage missing. Float and current meter recovered near Bermuda.

(e) Acoustic Release Failures.

No.	Site	Comments
178	D	ORE Fired on deck. Mooring aborted.
193	D	ORE Failed to trigger on command. Released by backup timer. Mooring recovered.
215	D	ORE Oversize ring jammed in release lock. Mooring not recovered.
238	P	ORE Failed to trigger on command. Mooring hauled with anchor. Nylon rope failed above release at 5400 m.
240	D	RAMACO Fired on deck. Mooring set and recovered without release.
241	D	Raytheon. Fired on deck. Mooring aborted.
251	D	ORE Failed to trigger on command. Released by backup timer. Mooring recovered.

(f) Causes Not Determined. Mooring not recovered; acoustic beacon not heard.

No.	Site	Comments
182	D	Subsurface float.
187	D	Subsurface float.
204	G	Gasoline float.
218	H	Gasoline float.
224	J	Subsurface float.

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Woods Hole Oceanographic Institution
Reference No. 68-12

CURRENT MEASUREMENTS FROM MOORED BUOYS by N. P. Fofonoff. PP. 409-418. March 1968. Contract N00014-66-C0241, NR 083-004.

Since January 1965, a program has been underway at the Woods Hole Oceanographic Institution, to measure currents at a limited number of fixed sites on a year round basis. Initially, one site was instrumented with both surface and subsurface moorings. The program has now been expanded to 4 major sites, extending along 70°W, from 39°20'N to the Hatteras Abyssal Plain at 30°N. In nearly three years of operation, a total of 65 moorings have been placed at the working sites, for periods up to six months. Recoveries from these sites have provided many velocity records of excellent quality.

The repetitive exposure of moorings of essentially similar design under relatively standardized conditions has served to define clearly the design and operational problems that are inherent in such a program.

A brief account is given of some of the problems encountered in routine buoy setting operations, and some of the results obtained from the measurements.

1. Mooring Performance
2. Recovery Statistics
3. Failure Modes

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